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(54) **POLYESTER RESIN USING RECYCLED BIS(2-HYDROXYETHYL)TEREPHTHALATE AND ARTICLE INCLUDING SAME**

(57) This polyester resin comprises a bis(2-hydroxyethyl)terephthalate monomer which is obtained by depolymerization of waste polyester and which has a diethylene glycol ester content adjusted to be a certain level

or less. The polyester resin, despite of being a recycled resin, has the same level of quality as the original resin and thus can be used in manufacturing articles in various fields.

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Description**Technical Field**

5 **[0001]** The present invention relates to a polyester resin prepared using recycled bis(2-hydroxyethyl) terephthalate (BHET) and to an article comprising the same.

Background Art

10 **[0002]** Polyester is widely used as a material for beverage-filling containers, packaging films, audio and video films, and the like by virtue of its excellent mechanical strength, thermal resistance, transparency, and gas barrier properties. In addition, polyester is widely produced worldwide as an industrial material such as medical fibers and tire cords. In particular, polyester sheets or plates have good transparency and excellent mechanical strength, so that they are widely used as raw materials for cases, boxes, partitions, shelves, panels, packaging materials, building materials, interior and exterior materials, and the like.

15 **[0003]** As a result, waste of plastics such as polyester is generated globally at an unmanageable level every year. Recently, countries around the world are preparing regulations and plans for recycling waste plastic resources, including waste polyester. Although physical or chemical methods are used as methods of recycling waste polyester, physical recycling methods cannot guarantee purity and are not widely used.

20 **[0004]** In chemical recycling methods, the ester bond of waste polyester is broken to depolymerize it. Reactions such as glycolysis, hydrolysis, methanolysis, and aminolysis are used. Glycolysis among them is to decompose waste polyester by adding a glycol such as ethylene glycol or diethylene glycol at high temperatures. A reaction product containing mainly bis(2-hydroxyethyl) terephthalate (BHET) is obtained.

25 **[0005]** The bis(2-hydroxyethyl) terephthalate may be used as a raw material for preparing unsaturated polyester or ester polyol after the crystallization or purification thereof.

[Prior Art Document]

[0006]

30 (Patent Document 1) Korean Patent No. 1386683
 (Patent Document 02) U.S. Patent No. 7211193
 (Non-patent Document 1) Park, S.H., Kim, S.H., Poly(ethylene terephthalate) recycling for high value added textiles, Fashion and Textiles 1, 1 (2014)

Disclosure of Invention**Technical Problem**

40 **[0007]** When a polyester resin is prepared using bis(2-hydroxyethyl) terephthalate (BHET) obtained through the depolymerization of waste polyester, there is a problem in that the quality of the final polyester product is deteriorated due to impurities in the BHET.

45 **[0008]** As a result of research conducted by the present inventors to solve this problem, it has been discovered that the content of diethylene glycol esters among impurities in BHET has an impact on the quality of a final polyester resin in association with the amount of BHET used for the polymerization of polyester.

[0009] Therefore, the present inventors use BHET, in which the content of diethylene glycol esters is adjusted to a certain level or less, and adjust the amount of BHET added to the polymerization of polyester and the glycol/acid ratio to prepare a regenerated polyester resin with excellent quality.

50 **[0010]** Accordingly, an object of the present invention is to provide a regenerated polyester resin having a quality equivalent to that of a virgin resin even though it is prepared through chemical recycling and an article comprising the same.

Solution to Problem

55 **[0011]** According to the present invention, there is provided a polyester resin, which comprises recycled bis(2-hydroxyethyl) terephthalate obtained through the depolymerization of waste polyester, wherein the recycled bis(2-hydroxyethyl) terephthalate has a peak area fraction of bis(2-hydroxyethyl) terephthalate of 96% or more and a peak area fraction of 2-hydroxyethyl[2-(2-hydroxyethoxy)ethyl] terephthalate of 2.5% or less, when measured by high-performance liquid chromatography (HPLC).

[0012] In addition, according to the present invention, there is provided a process for preparing a polyester resin, which comprises polymerizing a polyester resin using recycled bis(2-hydroxyethyl) terephthalate obtained through the depolymerization of waste polyester, wherein the recycled bis(2-hydroxyethyl) terephthalate has a peak area fraction of bis(2-hydroxyethyl) terephthalate of 96% or more and a peak area fraction of 2-hydroxyethyl[2-(2-hydroxyethoxy)ethyl] terephthalate of 2.5% or less, when measured by high-performance liquid chromatography (HPLC).

[0013] In addition, according to the present invention, there is provided an article, which comprises the polyester resin.

Advantageous Effects of Invention

[0014] Since the polyester resin according to the present invention comprises recycled BHET in which the content of diethylene glycol esters is adjusted to a certain level or less, even though it is a polyester resin regenerated through chemical recycling, it is hardly deteriorated in quality such as thermal resistance as compared with a virgin resin. In addition, according to the present invention, the quality of a final polyester resin can be effectively controlled by adjusting the content of recycled BHET and the glycol/acid ratio.

[0015] Accordingly, the polyester resin of the present invention can be used in the preparation of articles made of environmentally friendly materials in various fields.

Best Mode for Carrying out the Invention

[0016] Hereinafter, the present invention will be described in more detail.

[0017] In this specification, terms referring to the respective components are used to distinguish them from each other and are not intended to limit the scope of the embodiment. In addition, in the present specification, a singular expression is interpreted to cover a plural number as well unless otherwise specified in the context.

[0018] In the present specification, the terms first, second, and the like are used to describe various components. But the components should not be limited by the terms. The terms are used for the purpose of distinguishing one element from another.

[0019] In the present specification, the term "comprising" is intended to specify a particular characteristic, region, step, process, element, and/or component. It does not exclude the presence or addition of any other characteristic, region, step, process, element and/or component, unless specifically stated to the contrary.

Bis(2-hydroxyethyl) terephthalate

[0020] The polyester resin according to the present invention comprises bis(2-hydroxyethyl) terephthalate obtained by the depolymerization of waste polyester.

[0021] Bis(2-hydroxyethyl) terephthalate is an ester of two ethylene glycols and one terephthalic acid. For example, it is a compound formed as an intermediate in the process of preparing polyester such as polyethylene terephthalate (PET) through the polymerization of ethylene glycol and terephthalic acid or its ester.

[0022] Bis(2-hydroxyethyl) terephthalate (BHET), which is used as a polymerization raw material for the polyester resin according to the present invention, is obtained from waste polyester having a repeat unit of ethylene glycol and terephthalic acid like polyethylene terephthalate (PET) or glycol-modified polyethylene terephthalate (PETG). For example, it may be obtained by well-known depolymerization methods such as glycolysis, hydrolysis, and methanolysis.

[0023] In the present specification, bis(2-hydroxyethyl) terephthalate (BHET) obtained by the depolymerization of waste polyester as described above is referred to as "recycled bis(2-hydroxyethyl) terephthalate (recycled BHET)," or abbreviated as r-BHET or rBHET, which needs to be understood as distinct from a pure BHET compound.

[0024] Specifically, recycled BHET may contain reagents or solvents used in various chemical steps during the depolymerization of waste polyester, or by-products formed by side reactions with them. These impurities may remain in trace amounts even after several rounds of purification. Thus, recycled BHET generally contains trace amounts of organic and inorganic impurities in addition to BHET as the main component. For this reason, recycled BHET can also be viewed as a kind of composition comprising two or more components, i.e., a BHET composition.

[0025] Specifically, recycled BHET may comprise trace amounts of a heterogeneous organic component, such as BHET analogs such as monohydroxyethyl terephthalic acid (MHET), BHET dimers, BHET trimers, by-products such as diethylene glycol esters, metal ions as inorganic components, and residual solvent components in addition to BHET as the main component.

[0026] In the present invention, recycled BHET in which the content of such heterogeneous organic components is adjusted to a certain range is used. The content of each component in recycled BHET can be derived by measuring the fraction (%) of a peak area out of the total peak area in a spectrum obtained using high-performance liquid chromatography (HPLC).

[0027] Specifically, the recycled bis(2-hydroxyethyl) terephthalate (BHET) as a raw material in the present invention

has a peak area fraction of BHET of 96% or more when measured by high-performance liquid chromatography (HPLC). More specifically, the peak area fraction of BHET measured by HPLC may be 96.5% or more, 97% or more, 97.5% or more, or 98% or more.

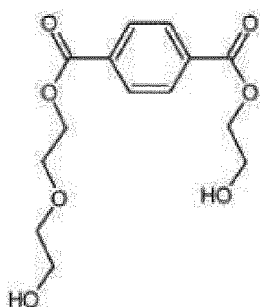
[0028] In addition, the recycled bis(2-hydroxyethyl) terephthalate may have a peak area fraction of organic impurities measured by HPLC of less than 5% in total, specifically, less than 4%, less than 3%, less than 2%, less than 1%, or less than 0.7%.

[0029] In particular, the polyester resin according to the present invention comprises recycled BHET in which the content of diethylene glycol esters (DEG esters) is adjusted to a certain level or less. For example, the recycled bis(2-hydroxyethyl) terephthalate may have a peak area fraction of diethylene glycol ester compounds of less than 2% in total when measured by HPLC. Specifically, the peak area fraction of diethylene glycol ester compounds may be less than 1.5%, less than 1%, less than 0.8%, or less than 0.7%, in total.

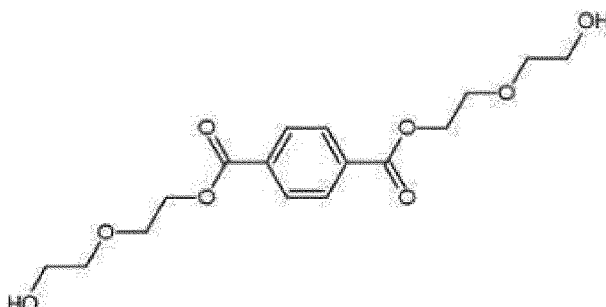
[0030] As an example, the diethylene glycol ester compounds may be a condensate between an aromatic dicarboxylic acid such as terephthalic acid and diethylene glycol. As another example, the diethylene glycol ester compounds may be a condensate between an aromatic dicarboxylic acid such as terephthalic acid and a glycol (e.g., ethylene glycol) in addition to diethylene glycol.

[0031] According to an embodiment, the recycled BHET may comprise 2-hydroxyethyl[2-(2-hydroxyethoxy)ethyl] terephthalate (CAS No. 65133-69-9) of the following Formula 1 as a first diethylene glycol ester. According to another embodiment, the recycled BHET may comprise bis[2-(2-hydroxyethoxy)ethyl]benzene-1,4-dicarboxylate (CAS No. 26850-76-0) of the following Formula 2 as a second diethylene glycol ester. If a polyester resin is prepared from recycled BHET in which the contents of the first diethylene glycol ester and the second diethylene glycol ester are adjusted to a certain level or less, even though it is a polyester resin recycled through chemical recycling, it is hardly deteriorated in quality as compared with a virgin resin.

[Formula 1]



[Formula 2]



[0032] According to an embodiment, the recycled bis(2-hydroxyethyl) terephthalate (BHET) has a peak area fraction of 2-hydroxyethyl[2-(2-hydroxyethoxy)ethyl] terephthalate (first diethylene glycol ester) of 2.5% or less when measured by high-performance liquid chromatography (HPLC). Specifically, the peak area fraction of 2-hydroxyethyl[2-(2-hydroxyethoxy)ethyl] terephthalate measured by HPLC may be 2.0% or less, 1.5% or less, 1.0% or less, or 0.5% or less.

[0033] According to another embodiment, the recycled bis(2-hydroxyethyl) terephthalate (BHET) has a peak area fraction of bis[2-(2-hydroxyethoxy)ethyl]benzene-1,4-dicarboxylate (second diethylene glycol ester) of 0.5% or less when measured by high-performance liquid chromatography (HPLC). Specifically, the peak area fraction of bis[2-(2-hydroxyethoxy)ethyl]benzene-1,4-dicarboxylate measured by HPLC may be 0.2% or less, more specifically, 0.15% or less, 0.1% or less, or 0.05% or less.

[0034] In addition, the recycled bis(2-hydroxyethyl) terephthalate may have a peak area fraction of oligomers of 3% or less in total when measured by HPLC.

[0035] Specifically, the recycled bis(2-hydroxyethyl) terephthalate may have a peak area fraction of BHET dimers of less than 3%, less than 2%, less than 1%, or less than 0.7%, when measured by HPLC. In addition, the recycled bis(2-hydroxyethyl) terephthalate produced by the above process may have a peak area fraction of BHET trimers of less than 1%, less than 0.5%, less than 0.3%, less than 0.1%, or 0%, when measured by HPLC.

[0036] In addition, the recycled bis(2-hydroxyethyl) terephthalate may further comprise impurities having a structure similar to that of bis(2-hydroxyethyl) terephthalate. For example, it may comprise at least one selected from the group consisting of monohydroxyethyl terephthalic acid (MHET), bis(2-hydroxypropyl) terephthalate, and monohydroxyethyl-ethoxy terephthalic acid. The impurities having a structure similar to that of bis(2-hydroxyethyl) terephthalate may have a peak area fraction of less than 3%, less than 2%, less than 1%, or less than 0.5%, when measured by HPLC.

[0037] In addition, the total content of residual solvents (e.g., ethylene glycol) in the recycled bis(2-hydroxyethyl) terephthalate may be less than 1% by weight based on a weight ratio detected by gas chromatography analysis. Spe-

cifically, the total content of residual solvents may be less than 0.5% by weight, less than 0.3% by weight, less than 0.2% by weight, less than 0.1% by weight, or less than 0.9% by weight.

[0038] In addition, the recycled bis(2-hydroxyethyl) terephthalate may have a yellow index (YID) of 3.0 or less as measured with a spectrophotometer in a solution of 25% by weight. Specifically, the yellow index may be 2.5 or less, 2.0 or less, 1.5 or less, or 1.0 or less.

[0039] In addition, the recycled bis(2-hydroxyethyl) terephthalate may have a total content of inorganic substances of less than 5 ppm as measured by inductively coupled plasma atomic emission spectroscopy (ICP-AES). Specifically, the total content of inorganic substances may be less than 3 ppm, less than 1 ppm, or nearly 0 ppm.

Composition of the polyester resin

[0040] The polyester resin of the present invention is a polyester resin regenerated through the chemical recycling of waste polyester.

[0041] Specifically, since the polyester resin of the present invention is polymerized using recycled BHET, it comprises a repeat unit derived from recycled BHET in the polymer chain.

[0042] The content of recycled BHET in the polyester resin of the present invention may be 1% by weight or more, 5% by weight or more, 10% by weight or more, 30% by weight or more, 50% by weight or more, 70% by weight or more, or 90% by weight or more. In addition, the content of recycled BHET may be 100% by weight or less, 99% by weight or less, 80% by weight or less, 60% by weight or less, 40% by weight or less, or 20% by weight or less.

[0043] As an example, the recycled bis(2-hydroxyethyl) terephthalate may be employed in an amount of 5% by weight to 99% by weight based on the weight of the polyester resin.

[0044] Meanwhile, since bis(2-hydroxyethyl) terephthalate has a structure in which two ethylene glycols and one terephthalic acid are bonded, the polyester resin of the present invention may essentially comprise a repeat unit derived from ethylene glycol and terephthalic acid.

[0045] As described above, the polyester resin of the present invention comprises a diacid component and a glycol component as monomers constituting the same. In addition, the polyester resin of the present invention may further comprise an additional diacid component and an additional glycol component for the polymerization of polyester.

[0046] In the polyester resin of the present invention, the diacid component may be a dicarboxylic acid or a derivative thereof, and the glycol component may be a diol.

[0047] In particular, the dicarboxylic acid comprises terephthalic acid, and the physical properties such as thermal resistance, chemical resistance, and weather resistance of a polyester resin can be enhanced by terephthalic acid. For example, terephthalic acid may be employed in an amount of 5% by mole to 100% by mole based on the number of moles of the entire dicarboxylic acid. In addition, the terephthalic acid component may be formed from a terephthalic acid alkyl ester such as dimethyl terephthalic acid.

[0048] In addition, the diol comprises ethylene glycol, and ethylene glycol may contribute to enhancing the transparency and impact resistance of a polyester resin. For example, ethylene glycol may be employed in an amount of 5% by mole to 100% by mole based on the number of moles of the entire diol.

[0049] According to an embodiment, the polyester resin of the present invention may be a copolymerized resin comprising two or more dicarboxylic acid components and/or two or more diol components.

[0050] Specifically, the dicarboxylic acid component may further comprise an aromatic dicarboxylic acid component, an aliphatic dicarboxylic acid component, or a mixture thereof, other than terephthalic acid. The dicarboxylic acid other than terephthalic acid may be employed in an amount of 1% by mole to 30% by mole based on the weight of the entire dicarboxylic acid components.

[0051] The aromatic dicarboxylic acid component may be an aromatic dicarboxylic acid having 8 to 20 carbon atoms, preferably, 8 to 14 carbon atoms, or a mixture thereof. Examples of the aromatic dicarboxylic acid include isophthalic acid, naphthalenedicarboxylic acids such as 2,6-naphthalenedicarboxylic acid, diphenyl dicarboxylic acid, 4,4'-stilbenedicarboxylic acid, 2,5-furandicarboxylic acid, 2,5-thiophenedicarboxylic acid, and the like, but it is not limited thereto.

[0052] The aliphatic dicarboxylic acid component may be an aliphatic dicarboxylic acid having 4 to 20 carbon atoms, preferably, 4 to 12 carbon atoms, or a mixture thereof. Examples of the aliphatic dicarboxylic acid include linear, branched, or cyclic aliphatic dicarboxylic acid components such as cyclohexanedicarboxylic acids such as 1,4-cyclohexanedicarboxylic acid and 1,3-cyclohexanedicarboxylic acid, phthalic acid, sebacic acid, succinic acid, isodecylsuccinic acid, maleic acid, fumaric acid, adipic acid, glutaric acid, azelaic acid, and the like, but it is not limited thereto.

[0053] In addition, the diol component may further comprise a comonomer other than ethylene glycol. The comonomer may comprise, for example, at least one selected from the group consisting of cyclohexanedimethanol, cyclohexanedimethanol derivatives, isosorbide, and diethylene glycol.

[0054] The cyclohexanedimethanol (e.g., 1,2-cyclohexanedimethanol, 1,3-cyclohexanedimethanol, and 1,4-cyclohexanedimethanol) may contribute to enhancing the transparency and impact resistance of a polyester resin produced. For example, cyclohexanedimethanol may be employed in an amount of 5% by mole to 90% by mole based on the number

of moles of the entire diol.

[0055] The cyclohexanedimethanol derivative may be 4-(hydroxymethyl)cyclohexylmethyl-4-(hydroxymethyl)cyclohexanecarboxylate or 4-(4-(hydroxymethyl)cyclohexylmethoxymethyl)cyclohexylmethanol. The cyclohexanedimethanol derivatives may be employed in an amount of 0.1% by mole to 25% by mole based on the number of moles of the entire diol.

[0056] Isosorbide may enhance the processability of the final polyester resin. Although the transparency and impact resistance of a polyester resin are enhanced by the diol component of cyclohexanedimethanol and ethylene glycol, shear fluidization characteristics should be improved and the crystallization rate should be delayed for processability; however, it is difficult to achieve this effect with cyclohexanedimethanol and ethylene glycol alone. Thus, if isosorbide is employed as a diol component, the shear fluidization characteristics are improved and the crystallization rate is delayed while transparency and impact resistance are maintained, whereby it is possible to improve the processability of a polyester resin produced. Preferably, isosorbide may be employed in an amount of 0.1% by mole to 50% by mole based on the number of moles of the entire diol.

[0057] As a specific example, the polyester resin comprises a diacid component and a glycol component, wherein the diacid component may comprise at least one selected from the group consisting of terephthalic acid, isophthalic acid, dimethyl isophthalate, phthalic acid, dimethyl phthalate, phthalic anhydride, 2,6-naphthalenedicarboxylic acid, dimethyl 2,6-naphthalenedicarboxylate, diphenyl dicarboxylic acid, 1,4-cyclohexanedicarboxylic acid, 1,3-cyclohexanedicarboxylic acid, dimethyl 1,4-cyclohexanedicarboxylate, dimethyl 1,3-cyclohexanedicarboxylate, sebacic acid, succinic acid, isodecylsuccinic acid, maleic acid, maleic anhydride, fumaric acid, adipic acid, glutaric acid, and azelaic acid, and the glycol component may comprise at least one selected from the group consisting of isosorbide (ISB), ethylene glycol, 1,2-propanediol, 1,3-propanediol, 2-methyl-1,3-propanediol, 2-methylene-1,3-propanediol, 2-ethyl-1,3-propanediol, 2-isopropyl-1,3-propanediol, 2,2-dimethyl-1,3-propanediol, 1,4-butanediol, 2,3-butanediol, 3-methyl-1,5-pentanediol, 3-methyl-2,4-pentanediol, 1,6-hexanediol, 1,2-cyclohexanediol, 1,4-cyclohexanediol, diethylene glycol, 4-(hydroxymethyl)cyclohexylmethyl-4-(hydroxymethyl)cyclohexanecarboxylate, and 4-(4-(hydroxymethyl)cyclohexylmethoxymethyl)cyclohexylmethanol.

Characteristics of the polyester resin

[0058] According to the present invention, it is possible to provide a polyester resin having more enhanced quality such as thermal resistance by adjusting the content of recycled BHET and the glycol/acid ratio in the polyester resin.

[0059] In particular, according to the present invention, a thermal resistance index of a final polyester resin calculated from the content of impurities such as diethylene glycol esters in recycled BHET associated with the amount of BHET used for the polymerization of polyester is adjusted to a specific range.

[0060] According to an embodiment, a first thermal resistance index is calculated using the composition (contents of BHET and DEG esters) of the recycled BHET and the content of the recycled BHET in a polyester resin as parameters. The first thermal resistance index may be adjusted within a specific range. The first thermal resistance index is a thermal resistance index derived from recycled BHET supplied to the polymerization of a polyester resin, which is a numerical value of the decrease in thermal resistance caused by DEG impurities in the recycled BHET. If the first thermal resistance index is adjusted to a certain level or less, it may be controlled to have a level of thermal resistance similar to that of a virgin polyester resin polymerized from an acid and a glycol.

[0061] Specifically, the polyester resin has a first thermal resistance index of 1.0 or less as calculated by the following Equation (1).

$$\text{First thermal resistance index} = \frac{(DEG_1 + 2 \times DEG_2) \times rBHET}{BHET_0} \dots (1)$$

[0062] In Equation (1), DEG_1 , DEG_2 , and $BHET_0$ are each the peak area fraction (%) of 2-hydroxyethyl[2-(2-hydroxyethoxy)ethyl] terephthalate, bis[2-(2-hydroxyethoxy)ethyl]benzene-1,4-dicarboxylate, and bis(2-hydroxyethyl) terephthalate, when the recycled bis(2-hydroxyethyl) terephthalate is measured by high-performance liquid chromatography (HPLC), and $rBHET$ is the weight fraction (%) of recycled bis(2-hydroxyethyl) terephthalate in the polyester resin. Only numerical values of these parameters (DEG_1 , DEG_2 , $BHET_0$, $rBHET$), exclusive of their units, are put in Equation (1) to calculate the first thermal resistance index (without a unit).

[0063] For example, the first thermal resistance index may be 1.0 or less, 0.9 or less, 0.8 or less, 0.7 or less, 0.6 or less, 0.5 or less, 0.4 or less, 0.3 or less, 0.2 or less, or 0.1 or less. In addition, the first thermal resistance index may be 0 or more, 0.1 or more, 0.2 or more, 0.3 or more, 0.4 or more, or 0.5 or more. As a specific example, the first thermal resistance index may be 0 to 1.0 or 0.1 to 1.0.

[0064] According to another embodiment, a second thermal resistance index is calculated using the molar ratio of

glycol and diacid in the monomers constituting the polyester resin as parameters. The second thermal resistance index may be adjusted within a specific range. The second thermal resistance index is a numerical value related to the content of glycol and acid constituting the polyester resin. If the second thermal resistance index is adjusted, it is possible to polymerize a polyester resin without deterioration in thermal resistance even when a large amount of recycled BHET is used.

[0065] Specifically, the polyester resin has a second thermal resistance index of 1.6 or less as calculated by the following Equation (2).

$$\text{Second thermal resistance index} = (G/A) \times 0.32 + 0.83 \dots (2)$$

[0066] In Equation (2), G and A are each the number of moles of glycol and the number of moles of diacid in the monomers constituting the polyester resin, and G/A is the mole ratio of glycol to diacid.

[0067] For example, the second thermal resistance index may be 1.6 or less, 1.5 or less, 1.4 or less, 1.3 or less, or 1.2 or less. In addition, the second thermal resistance index may be 0 or more, 0.5 or more, 1.0 or more, 1.1 or more, 1.2 or more, or 1.3 or more. As a specific example, the second thermal resistance index may be 0 to 1.6 or 1.0 to 1.6.

[0068] According to another embodiment, a third thermal resistance index is calculated using the first thermal resistance index and the second thermal resistance index as parameters. The third thermal resistance index may be adjusted within a specific range. Since the third thermal resistance index comprehensively considers the quality and amount of recycled BHET and the glycol/acid content of the polyester resin, it is possible to more effectively control the thermal resistance of a final polyester resin by adjusting the third thermal resistance index.

[0069] Specifically, the polyester resin has a third thermal resistance index of 2.6 or less as calculated by the following Equation (3).

$$\text{Third thermal resistance index} = \text{first thermal resistance index} + \text{second thermal resistance index} \quad (3)$$

[0070] For example, the third thermal resistance index may be 2.6 or less, 2.5 or less, 2.4 or less, 2.3 or less, 2.2 or less, 2.1 or less, 2.0 or less, 1.9 or less, 1.8 or less, 1.7 or less, 1.6 or less, 1.5 or less, 1.4 or less, or 1.3 or less. In addition, the third thermal resistance index may be 0 or more, 0.5 or more, 1.0 or more, 1.5 or more, 1.7 or more, or 1.9 or more. As a specific example, the third thermal resistance index may be 0 to 2.6 or 1.0 to 2.6.

[0071] A polyester resin whose thermal resistance indices are adjusted may be hardly deteriorated in thermal resistance as compared with a virgin polyester resin.

[0072] According to an embodiment, the polyester resin according to the present invention may have a ΔT_g of 3.0 or less as calculated by the following equation. Specifically, ΔT_g according to the following equation may be 2.5 or less. Specifically, ΔT_g according to the following equation may be 2.0 or less or 1.5 or less.

$$\Delta T_g (\text{°C}) = T_{g1} - T_{g2}$$

[0073] Here, T_{g2} is the glass transition temperature (°C) of a polyester resin polymerized using recycled BHET, and T_{g1} is the glass transition temperature (°C) of a polyester resin polymerized using ethylene glycol and terephthalic acid in molar equivalents to the recycled BHET.

[0074] The polyester resin according to the present invention may have an intrinsic viscosity (IV) at 35°C of 0.5 dl/g to 1.2 dl/g. For example, the intrinsic viscosity of the polyester resin at 35°C may be 0.50 dl/g to 1.0 dl/g, 0.50 dl/g to 0.85 dl/g, or 0.55 dl/g to 0.80 dl/g. Specifically, the polyester resin may have a melt intrinsic viscosity (melt IV) at 35°C of 0.5 dl/g to 1.2 dl/g or 0.75 dl/g to 1.0 dl/g. In addition, the polyester resin may have a solid-phase intrinsic viscosity (solid-phase IV) at 35°C of 0.7 dl/g to 1.2 dl/g or 1.0 dl/g to 1.2 dl/g. The melt intrinsic viscosity is an intrinsic viscosity measured after the melt-polymerization of the polyester resin (before solid-phase polymerization). The solid-phase intrinsic viscosity is an intrinsic viscosity measured after melt-polymerization and solid-phase polymerization of the polyester resin.

[0075] The polyester resin according to the present invention can be used as a material for beverage-filling containers, packaging films, audio and video films, and the like by virtue of its excellent mechanical strength, thermal resistance, transparency, and gas barrier properties. In particular, polyester sheets or plates prepared from the polyester resin according to the present invention have good transparency and excellent mechanical strength, so that they can be used as raw materials for cases, boxes, partitions, shelves, panels, packaging materials, building materials, interior and exterior materials, and the like. In addition, the polyester resin according to the present invention can be used as an industrial material such as medical fibers and tire cords.

[0076] Accordingly, the present invention also provides an article, which comprises the polyester resin.

Process for preparing a polyester resin

[0077] The process for preparing a polyester resin according to the present invention comprises polymerizing a polyester resin using recycled bis(2-hydroxyethyl) terephthalate (BHET) obtained through the depolymerization of waste polyester, wherein the recycled bis(2-hydroxyethyl) terephthalate has a peak area fraction of bis(2-hydroxyethyl) terephthalate of 96% or more and a peak area fraction of 2-hydroxyethyl[2-(2-hydroxyethoxy)ethyl] terephthalate (a first diethylene glycol ester) of 2.5% or less, when measured by high-performance liquid chromatography (HPLC).

[0078] The polyester resin according to the present invention may be prepared by further adding terephthalic acid or a derivative thereof and/or ethylene glycol in addition to the recycled bis(2-hydroxyethyl) terephthalate. In addition, the polyester resin may be prepared as a copolymer by further adding comonomers of other diacids and/or glycols.

[0079] In the polymerization, an esterification reaction (step 1) and a polycondensation reaction (step 2) may be sequentially carried out.

[0080] The esterification reaction is carried out in the presence of an esterification reaction catalyst, and an esterification reaction catalyst containing a zinc-based compound may be used. Specific examples of the zinc-based catalyst include zinc acetate, zinc acetate hydrate, zinc chloride, zinc sulfate, zinc sulfide, zinc carbonate, zinc citrate, zinc gluconate, or mixtures thereof.

[0081] The esterification reaction may be carried out, for example, at a pressure of 0 kgf/cm² to 10.0 kgf/cm² and a temperature of 150°C to 300°C. The esterification reaction conditions may be appropriately adjusted according to the specific characteristics of the polyester to be produced, the ratio of each component, or process conditions. Specifically, the pressure in the esterification reaction may be 0 kg/cm² to 5.0 kg/cm², more specifically, 0.1 kg/cm² to 3.0 kg/cm². In addition, the temperature in the esterification reaction may be 200°C to 270°C, more specifically, 240°C to 260°C.

[0082] The esterification reaction may be carried out in a batch or continuous type. Although each of the raw materials may be separately fed, it is preferable to feed them in the form of a slurry in which a diol component, a dicarboxylic acid component, and recycled BHET are mixed. In addition, a diol component such as isosorbide, which is solid at room temperature, may be dissolved in water or ethylene glycol and then mixed with a dicarboxylic acid component such as terephthalic acid to prepare a slurry. Alternatively, isosorbide is melted at 60°C or higher, which is then mixed with a dicarboxylic acid component such as terephthalic acid and other diol components to prepare a slurry. In addition, water may be additionally added to the mixed slurry to help increase the fluidity of the slurry.

[0083] The polycondensation reaction may be carried out, for example, by reacting the esterification reaction product at a temperature of 150°C to 300°C and under a reduced pressure condition of 0.01 mmHg to 600 mmHg for 1 hour to 24 hours.

[0084] The temperature in the polycondensation reaction may be 150°C to 300°C, specifically, 200°C to 290°C, more specifically, 260°C to 280°C. In addition, the pressure in the polycondensation reaction may be 0.01 mmHg to 600 mmHg, specifically, 0.05 mmHg to 200 mmHg, more specifically, 0.1 mmHg to 100 mmHg. As the reduced pressure condition is adopted in the polycondensation reaction, glycol, which is a by-product of the polycondensation reaction, can be removed from the system. If the pressure in the polycondensation reaction exceeds the range of 0.01 mmHg to 400 mmHg, the removal of by-products may be insufficient. In addition, if the temperature in the polycondensation reaction is lower than 150°C, a glycol as a by-product of the reaction cannot be effectively removed from the system; thus, the intrinsic viscosity of a final reaction product is low, resulting in a decrease in physical properties of the final polyester resin. If the temperature in the condensation polymerization reaction exceeds 300°C, the possibility of yellowing of a final polyester resin increases. In addition, the polycondensation reaction may be carried out for a necessary period of time, for example, an average residence time of 1 hour to 24 hours, until the intrinsic viscosity of a final reaction product reaches an appropriate level.

[0085] In addition, a polycondensation catalyst comprising a titanium-based compound, a germanium-based compound, an antimony-based compound, an aluminum-based compound, a tin-based compound, or a mixture thereof may be used in the polycondensation reaction.

[0086] Examples of the titanium compound include tetraethyl titanate, acetyltripropyl titanate, tetrapropyl titanate, tetrabutyl titanate, 2-ethylhexyl titanate, octylene glycol titanate, lactate titanate, triethanolamine titanate, acetylacetone titanate, ethylacetoacetic ester titanate, isostearyl titanate, titanium dioxide, and the like. Examples of the germanium-based compound include germanium dioxide, germanium tetrachloride, germanium ethylene glycoside, germanium acetate, or mixtures thereof. Preferably, germanium dioxide can be used. Both crystalline and amorphous germanium dioxide may be used, and glycol-soluble ones may also be used.

[0087] The polycondensation reaction may produce a relatively low molecular weight polyester resin through melt polymerization. In addition, a polyester resin having a relatively high molecular weight may be produced through solid-state polymerization after the melt polymerization.

Process for preparing recycled BHET

[0088] Although bis(2-hydroxyethyl) terephthalate used in the preparation of the polyester resin according to the present invention is a recycled monomer obtained by the depolymerization of waste polyester, it has high purity and a low content of impurities such as diethylene glycol esters.

[0089] Such bis(2-hydroxyethyl) terephthalate can be obtained by carrying out the depolymerization reaction in multiple stages, while significantly lowering the temperature of the latter stage, followed by ion exchange and distillation of an unreacted glycol after the depolymerization reaction.

[0090] The process for preparing recycled bis(2-hydroxyethyl) terephthalate according to an embodiment may comprise (1) subjecting waste polyester to depolymerization by a first glycolysis reaction at a temperature of 180°C to 200°C to obtain a first reactant; (2) subjecting the first reactant to depolymerization by a second glycolysis reaction at a temperature of 150°C to 170°C to obtain a second reactant; (3) subjecting the second reactant to ion exchanging through an ion-exchange resin to obtain a third reactant; (4) removing an unreacted glycol from the third reactant through distillation at a temperature of 150°C or lower to obtain a fourth reactant; and (5) subjecting the fourth reactant to distillation to obtain crude bis(2-hydroxyethyl) terephthalate.

[0091] According to the above process, bis(2-hydroxyethyl) terephthalate (BHET) can be produced with high purity by carrying out the depolymerization reaction in multiple stages, while significantly lowering the temperature of the latter stage, thereby reducing the formation of diethylene glycol and impurities derived therefrom. In addition, according to the above process, it is possible to prepare bis(2-hydroxyethyl) terephthalate (BHET) with enhanced quality in terms of color by further carrying out ion exchange and distillation of an unreacted glycol after the depolymerization reaction, thereby reducing the formation of oligomers and removing chromophores.

[0092] According to another embodiment, prior to step (1), a step of pulverizing the waste polyester to a size of a certain level or below may be further carried out. The waste polyester may have a particulate or fibrous form with a particle diameter of 4 mm or less. If the depolymerization is carried out as the particle diameter or diameter of waste polyester is adjusted within the specific range, solvation can be expedited even under the conditions of relatively low temperature and short reaction time.

[0093] According to another embodiment, the first glycolysis reaction in step (1) is carried out in the presence of a catalyst. The catalyst comprises a metal acetate or an anhydride or a hydride thereof. More specifically, it may be at least one selected from the group consisting of zinc acetate, sodium acetate, cobalt acetate, and manganese acetate, or in the form of a hydrate or anhydride thereof. In addition, the catalyst may be used in an amount of 0.2 part by weight to 0.4 part by weight relative to 100 parts by weight of the waste polyester.

[0094] According to another embodiment, a step of cooling the second reactant obtained in step (2) to a certain temperature or lower may be further carried out.

[0095] According to another embodiment, prior to the ion exchange in step (3), a step of removing insoluble foreign substances from the second reactant through filtration may be further carried out. Specifically, a step of cooling the second reactant to 120°C or lower and filtering it upon the addition of a filter aid may be further carried out.

[0096] According to another embodiment, prior to the ion exchange in step (3), a step of removing insoluble foreign substances from the second reactant through filtration may be further carried out.

[0097] According to another embodiment, the ion-exchange resin in step (3) is used in an amount of 1 part by weight to 20 parts by weight relative to 100 parts by weight of the waste polyester and comprises at least one selected from the group consisting of a strongly acidic cation-exchange resin, a weakly acidic cation-exchange resin, and a chelate resin.

[0098] According to another embodiment, the distillation to remove an unreacted glycol in step (4) may be carried out at a temperature of 100°C to 130°C.

[0099] According to another embodiment, the distillation to obtain crude bis(2-hydroxyethyl) terephthalate in step (5) may be carried out by thin film evaporation under a pressure of 0.05 Torr to 0.4 Torr.

[0100] According to another embodiment, the process may further comprise, after the distillation in step (5), adsorbing-crystallizing the crude bis(2-hydroxyethyl) terephthalate. The adsorption-crystallization may be carried out by adding an adsorbent using water as a solvent, filtering, and crystallization.

[0101] According to a specific embodiment, first, waste polyester is pulverized to a size of 4 mm or less to be prepared, ethylene glycol is added thereto, which is then subjected to a first glycolysis reaction at a temperature of 180°C to 200°C in the presence of a zinc acetate catalyst for about 2 hours, and ethylene glycol is further added thereto, which is then subjected to a second glycolysis reaction at a temperature of 150°C to 170°C for about 2 hours. Thereafter, it is cooled to 120°C or lower using a reduced pressure flash, a small amount of a filter aid is added thereto, which is then filtered to separate insoluble foreign substances through solid-liquid separation, and it is passed through a column filled with ion-exchange resin to carry out ion exchange. Then, an unreacted glycol is recovered at a temperature of 100°C to 130°C, purification is carried out by thin film distillation at 190°C to 250°C, and, finally, an adsorption-crystallization step is carried out to obtain bis(2-hydroxyethyl) terephthalate with high purity and high quality.

[0102] According to the above process, a two-stage glycolysis reaction (i.e., a first glycolysis reaction and a second

glycolysis reaction) is carried out. If the solvation is expedited in the first glycolysis reaction, the transesterification reaction of the waste polyester can be performed under the conditions of lower temperatures and short reaction time in the second glycolysis reaction. Thus, it is possible to significantly reduce the concentration of diethylene glycol (DEG) naturally formed at a common glycolysis reaction temperature and to significantly reduce the content of diethylene glycol esters in bis(2-hydroxyethyl) terephthalate finally prepared.

Mode for the Invention

[0103] Hereinafter, the present invention will be described in more detail with reference to embodiments. However, these examples are provided only for illustration purposes, and the present invention is not limited thereto.

Preparation Example: r-BHET_A1 (recycled BHET)

[0104] A first reactor made of stainless steel (SUS) was charged with 1,000 g of a waste polyester resin pulverized to a particle size of 4 mm or less, 2,000 g of ethylene glycol, and 3.5 g of zinc acetate anhydride. The temperature inside the reactor was raised to 180°C, and depolymerization (first glycolysis reaction) was carried out for 2 hours. The reactant (first reactant) thus obtained was transferred to a second reactor and cooled to 150°C. 2,000 g of ethylene glycol was further added thereto, and depolymerization (second glycolysis reaction) was carried out for 2 hours while the reactor temperature was maintained at 150°C. The reactant (second reactant) thus obtained was cooled to 120°C through reduced pressure flash, and 16 g of a filter aid was added thereto, followed by pressurized filtration to carry out solid-liquid separation. The separated liquid reactant was passed through a column filled with an ion-exchange resin (BC107(H) of Bonlite) to remove ionic impurities to obtain a mixture (third reactant) containing bis(2-hydroxyethyl) terephthalate and ethylene glycol. The mixture (third reactant) was transferred to a 10-liter distillation apparatus, and vacuum distillation was carried out at 130°C to recover unreacted ethylene glycol. The reactant (fourth reactant) from which ethylene glycol had been removed was subjected to thin film evaporation at 220°C and 0.08 Torr in a thin film evaporator (VKL70-4S of VTA) to obtain 1,040 g of a product from which dimers or higher oligomers had been removed. Thereafter, for adsorption-crystallization, 1,040 g of the above product and 3,120 g of distilled water were charged to a 20-liter glass reactor, dissolved at a temperature of 70°C, and then 5.2 g of activated carbon was added thereto, followed by stirring for 30 minutes and filtration thereof. The filtrate was cooled to room temperature for the crystallization thereof, filtered, and dried in a vacuum oven. As a result, 990 g of a final product containing bis(2-hydroxyethyl) terephthalate was obtained.

Preparation Example: r-BHET_A2 (recycled BHET)

[0105] 980 g of a final product containing bis(2-hydroxyethyl) terephthalate (referred to as r-BHET_A2) was obtained through the same procedure as in the Preparation Example of r-BHET_A1, except that the first glycolysis reaction was carried out at 180°C for 1 hour.

Preparation Example: r-BHET_A3 (recycled BHET)

[0106] 985 g of a final product containing bis(2-hydroxyethyl) terephthalate (referred to as r-BHET_A3) was obtained through the same procedure as in the Preparation Example of r-BHET_A1, except that 1,000 g of a waste fiber was used as a raw material for waste polyester.

Preparation Example: r-BHET_A4 (recycled BHET)

[0107] 992 g of a final product containing bis(2-hydroxyethyl) terephthalate (referred to as r-BHET_A4) was obtained through the same procedure as in the Preparation Example of r-BHET_A1, except that 1,000 g of a waste banner was used as a raw material for waste polyester.

Preparation Example: r-BHET_A5 (recycled BHET)

[0108] 1,050 g of a final product containing bis(2-hydroxyethyl) terephthalate (referred to as r-BHET_A5) was obtained through the same procedure as in the Preparation Example of r-BHET_A1, except that no adsorption-crystallization step was carried out after the thin film evaporation.

Preparation Example: r-BHET_B1 (recycled BHET)

[0109] A reactor made of stainless steel (SUS) was charged with 1,000 g of a waste polyester resin having a particle

size of 4 mm or less, 4,000 g of ethylene glycol, and 3.5 g of zinc acetate anhydride. The temperature inside the reactor was raised to 196°C, and depolymerization (glycolysis reaction) was carried out for 4 hours. The reactant thus obtained was cooled to 30°C, and crystallization of bis(2-hydroxyethyl) terephthalate was carried out for 2 hours. The slurry of bis(2-hydroxyethyl) terephthalate and ethylene glycol thus obtained was subjected to solid-liquid separation in a centrifugal separator. Bis(2-hydroxyethyl) terephthalate obtained through centrifugation was washed twice with a sufficient amount of distilled water, and the residual solvent was removed in an oven to obtain about 1,010 g of a final product containing bis(2-hydroxyethyl) terephthalate (referred to as r-BHET_B1).

Preparation Example: r-BHET_B2 (recycled BHET)

[0110] About 1,000 g of a final product containing bis(2-hydroxyethyl) terephthalate (referred to as r-BHET_B2) was obtained through the same procedure as in the Preparation Example of r-BHET_B1, except that the glycolysis reaction was carried out at 210°C.

Preparation Example: r-BHET_B3 (recycled BHET)

[0111] About 1,020 g of a final product containing bis(2-hydroxyethyl) terephthalate (referred to as r-BHET_B3) was obtained through the same procedure as in the Preparation Example of r-BHET_A1, except that the first glycolysis reaction was carried out at 196°C for 4 hours and that neither the second glycolysis reaction nor the adsorption-crystallization was carried out.

Evaluation of recycled bis(2-hydroxyethyl) terephthalate

[0112] The resultants containing each recycled bis(2-hydroxyethyl) terephthalate prepared above were tested as follows. The results are summarized in Table 1 below.

(1) Composition - High-performance liquid chromatography (HPLC)

[0113] About 0.01 g of a sample was diluted in about 20 ml of methanol and then measured by HPLC.

- Model: Waters e2695
- Column: C18 (4.6 × 250 mm), 5 μm
- UV detector: 242 nm
- Injection volume: 10 μl
- Eluent (gradient) A: H₂O+H₃PO₄, B: acetonitrile

(2) Residual solvent - Gas chromatography (GC)

[0114] About 0.1 g of a sample was diluted in about 10 ml of CHCl₃, treated with a filter of 0.45 μm, and then measured by GC.

- Model: Agilent 7890B
- Column: DB-624 (30 m × 0.25 mm × 1.4 μm)
- Oven Temp.: 60°C (2 min) - 10°C/min - 200°C (0 min) - 20°C/min - 260°C (5 min)
- Injector temp.: 250°C
- Detector temp.: 250°C
- Flow: 1.5 ml/min (N₂), split ratio: 1/50

(3) Yellow index (YID)

[0115] A sample was dissolved in dimethylformamide (DMF) at a concentration of 25% by weight at room temperature (23°C) to prepare a solution. Transmission data were obtained with Illuminant D65 using Color Flex EZ of Hunterlab at an observer's angle of 2° for the solution. The YID value was calculated using a color analyzer in the software.

[Table 1]

		r-BHET							
		A1	A2	A3	A4	A5	B1	B2	B3
HPLC (Area %)	BHET	98.21	98.2	97.84	96.58	96.76	82.55	84.58	90.68
	MHET	1.09	1.08	1.1	1.72	1.89	1	2.18	1.66
	DEG ester 1*	0.44	0.43	0.62	0.61	0.8	3.67	5.35	2.88
	DEG ester 2*	0	0	0.16	0.09	0.1	0.38	0.27	0.25
	Dimer	0.2	0.19	0.22	0.84	0.23	10.44	6.36	3.68
	Trimer	0	0	0	0	0	0.89	0.72	0.35
	Others	0.06	0.1	0.06	0.16	0.22	1.07	0.54	0.5
GC	Residual EG (wt. %)	0.07	0.07	0.08	0.07	0.23	0.41	0.45	0.33
YID	r-BHET solution	0.59	1.23	1.56	2.73	2.38	5.4	6.7	5.5
* DEG ester 1: 2-hydroxyethyl[2-(2-hydroxyethoxy)ethyl] terephthalate * DEG ester 2: bis[2-(2-hydroxyethoxy)ethyl]benzene-1,4-dicarboxylate									

[0116] As can be seen from the above table, in r-BHET_A1 to r-BHET_A5, the ratio of BHET was high, no inorganic impurities were observed, the YID value was low, and the content of DEG-derived esters was very low. In contrast, r-BHET_B1 to r-BHET_B3 each had problems in that they contained a large amount of dimers or DEG-derived esters, had poor color quality due to a high yellowness index (YID), or had some residual solvents.

Example 1: Preparation of a polyester resin

[0117] A 10-liter reactor equipped with a column and a condenser that can be cooled by water was charged with recycled bis(2-hydroxyethyl) terephthalate (r-BHET_A1, 1,905.2 g), terephthalic acid (TPA, 2,905.3 g), ethylene glycol (EG, 666.6 g), 1,4-cyclohexanedimethanol (CHDM, 432.0 g), and isosorbide (ISB, 146.0 g), followed by the addition thereto of GeO₂ (6.4 g) as a catalyst, phosphoric acid (10.0 g) as a stabilizer, a blue toner (0.005 g), and a red toner (0.003 g).

[0118] Subsequently, nitrogen was injected into the reactor to make the reactor pressurized by 1.0 kgf/cm² higher than normal pressure (absolute pressure: 1,495.6 mmHg). Then, the temperature of the reactor was raised to 220°C over 90 minutes and maintained at 220°C for 2 hours, and the temperature was then raised again to 255°C over 2 hours. Thereafter, an esterification reaction was carried out at a temperature of 260°C while the mixture in the reactor was visually observed until the mixture became transparent. In this procedure, by-products were discharged through the column and condenser. Upon completion of the esterification reaction, nitrogen in the pressurized reactor was released to the outside to lower the pressure in the reactor to normal pressure, and the mixture in the reactor was then transferred to a 7-liter reactor capable of a reaction under vacuum.

[0119] Then, the pressure of the reactor was reduced from normal pressure to 5 Torr (absolute pressure: 5 mmHg) over 30 minutes. At the same time, the temperature of the reactor was raised to 272°C over 1 hour, and a polycondensation reaction was carried out while the pressure of the reactor was maintained at 1 Torr (absolute pressure: 1 mmHg) or less. At the beginning of the polycondensation reaction, the stirring speed may be set high. As the polycondensation reaction proceeds, when the stirring power is weakened due to the increase in the viscosity of the reactants or the temperature of the reactants rises above the set temperature, the stirring speed may be appropriately adjusted accordingly. The polycondensation reaction was carried out until the intrinsic viscosity (IV) of the mixture (melt) in the reactor reached 0.70 dl/g. When the intrinsic viscosity of the mixture in the reactor reached the desired level, the mixture was then discharged to the outside of the reactor to form strands, which were solidified with a cooling liquid and then granulated to have an average weight of about 12 to 14 mg.

[0120] The granules were left at 150°C for 1 hour to be crystallized, which were then fed to a 20-liter reactor for a solid-phase polymerization. Thereafter, nitrogen flowed into the reactor at a rate of 50 liters/minute. In such an event, the temperature of the reactor was raised from room temperature to 190°C at a rate of 40°C/hour and maintained at 190°C. The solid-phase polymerization reaction was carried out until the intrinsic viscosity (IV) of the granules in the reactor reached 1.20 dl/g to prepare a polyester resin (copolymer).

Example 2: Preparation of a polyester resin

[0121] A 10-liter reactor equipped with a column and a condenser that can be cooled by water was charged with recycled bis(2-hydroxyethyl) terephthalate (r-BHET_A2, 6,441.5 g), EG (26.2 g), CHDM (182.6 g), and ISB (49.4 g), followed by the addition thereto of GeO₂ (3.2 g), a blue toner (0.015 g), and a red toner (0.008 g).

[0122] Subsequently, nitrogen was injected into the reactor to make the reactor pressurized by 2.0 kgf/cm² higher than normal pressure. Then, the temperature of the reactor was raised to 220°C over 90 minutes and maintained at 220°C for 2 hours, and the temperature was then raised again to 255°C over 2 hours. Thereafter, an esterification reaction was carried out at a temperature of 260°C while the mixture in the reactor was visually observed until the mixture became transparent. In this procedure, by-products were discharged through the column and condenser. Upon completion of the esterification reaction, nitrogen in the pressurized reactor was released to the outside to lower the pressure in the reactor to normal pressure, and the mixture in the reactor was then transferred to a 7-liter reactor capable of a reaction under vacuum.

[0123] Then, the pressure of the reactor was reduced from normal pressure to 5 Torr (absolute pressure: 5 mmHg) over 30 minutes. At the same time, the temperature of the reactor was raised to 280°C over 1 hour, and a polycondensation reaction was carried out while the pressure of the reactor was maintained at 1 Torr (absolute pressure: 1 mmHg) or less. At the beginning of the polycondensation reaction, the stirring speed may be set high. As the polycondensation reaction proceeds, when the stirring power is weakened due to the increase in the viscosity of the reactants or the temperature of the reactants rises above the set temperature, the stirring speed may be appropriately adjusted accordingly. The polycondensation reaction was carried out until the intrinsic viscosity (IV) of the mixture (melt) in the reactor reached 0.60 dl/g. When the intrinsic viscosity of the mixture in the reactor reached the desired level, the mixture was then discharged to the outside of the reactor to form strands, which were solidified with a cooling liquid and then granulated to have an average weight of about 12 to 14 mg.

[0124] The granules were left at 150°C for 1 hour to be crystallized, which were then fed to a 20-liter reactor for a solid-phase polymerization. Thereafter, nitrogen flowed into the reactor at a rate of 50 liters/minute. In such an event, the temperature of the reactor was raised from room temperature to 200°C at a rate of 40°C/hour and maintained. The solid-phase polymerization reaction was carried out until the intrinsic viscosity (IV) of the granules in the reactor reached 0.85 dl/g to prepare a polyester resin (copolymer).

Example 3: Preparation of a polyester resin

[0125] A 10-liter reactor equipped with a column and a condenser that can be cooled by water was charged with recycled bis(2-hydroxyethyl) terephthalate (r-BHET_A3, 4,814.5 g), TPA (1,048.8 g), EG (47.0 g), and CHDM (72.8 g), followed by the addition thereto of GeO₂ (3.2 g), a TiO₂/SiO₂ coprecipitate (0.4 g), phosphoric acid (1.0 g), a blue toner (0.020 g), and a red toner (0.005 g).

[0126] Subsequently, nitrogen was injected into the reactor to make the reactor pressurized by 0.5 kgf/cm² higher than normal pressure. Then, the temperature of the reactor was raised to 220°C over 90 minutes and maintained at 220°C for 2 hours, and the temperature was then raised again to 255°C over 2 hours. Thereafter, an esterification reaction was carried out at a temperature of 260°C while the mixture in the reactor was visually observed until the mixture became transparent. In this procedure, by-products were discharged through the column and condenser. Upon completion of the esterification reaction, nitrogen in the pressurized reactor was released to the outside to lower the pressure in the reactor to normal pressure, and the mixture in the reactor was then transferred to a 7-liter reactor capable of a reaction under vacuum.

[0127] Then, the pressure of the reactor was reduced from normal pressure to 5 Torr (absolute pressure: 5 mmHg) over 30 minutes. At the same time, the temperature of the reactor was raised to 275°C over 1 hour, and a polycondensation reaction was carried out while the pressure of the reactor was maintained at 1 Torr (absolute pressure: 1 mmHg) or less. At the beginning of the polycondensation reaction, the stirring speed may be set high. As the polycondensation reaction proceeds, when the stirring power is weakened due to the increase in the viscosity of the reactants or the temperature of the reactants rises above the set temperature, the stirring speed may be appropriately adjusted accordingly. The polycondensation reaction was carried out until the intrinsic viscosity (IV) of the mixture (melt) in the reactor reached 0.70 dl/g. When the intrinsic viscosity of the mixture in the reactor reached the desired level, the mixture was then discharged to the outside of the reactor to form strands, which were solidified with a cooling liquid and then granulated to have an average weight of about 12 to 14 mg to prepare a polyester resin (copolymer).

Example 4: Preparation of a polyester resin

[0128] A 10-liter reactor equipped with a column and a condenser that can be cooled by water was charged with recycled bis(2-hydroxyethyl) terephthalate (r-BHET_A4, 634.1 g), TPA (3,729.8 g), EG (1,300.2 g), CHDM (215.7 g),

and diethylene glycol (DEG, 182.2 g), followed by the addition thereto of a $\text{TiO}_2/\text{SiO}_2$ coprecipitate (0.2 g), phosphoric acid (2.0 g), and cobalt acetate (1.1 g).

[0129] Subsequently, nitrogen was injected into the reactor to make the reactor pressurized by 1.0 kgf/cm² higher than normal pressure (absolute pressure: 1,495.6 mmHg). Then, the temperature of the reactor was raised to 220°C over 90 minutes and maintained at 220°C for 2 hours, and the temperature was then raised again to 245°C over 2 hours. Thereafter, an esterification reaction was carried out at a temperature of 250°C while the mixture in the reactor was visually observed until the mixture became transparent. In this procedure, by-products were discharged through the column and condenser. Upon completion of the esterification reaction, nitrogen in the pressurized reactor was released to the outside to lower the pressure in the reactor to normal pressure, and the mixture in the reactor was then transferred to a 7-liter reactor capable of a reaction under vacuum.

[0130] Then, the pressure of the reactor was reduced from normal pressure to 5 Torr (absolute pressure: 5 mmHg) over 30 minutes. At the same time, the temperature of the reactor was raised to 265°C over 1 hour, and a polycondensation reaction was carried out while the pressure of the reactor was maintained at 1 Torr (absolute pressure: 1 mmHg) or less. At the beginning of the polycondensation reaction, the stirring speed may be set high. As the polycondensation reaction proceeds, when the stirring power is weakened due to the increase in the viscosity of the reactants or the temperature of the reactants rises above the set temperature, the stirring speed may be appropriately adjusted accordingly. The polycondensation reaction was carried out until the intrinsic viscosity (IV) of the mixture (melt) in the reactor reached 0.60 dl/g. When the intrinsic viscosity of the mixture in the reactor reached the desired level, the mixture was then discharged to the outside of the reactor to form strands, which were solidified with a cooling liquid and then granulated to have an average weight of about 12 to 14 mg.

[0131] The granules were left at 150°C for 1 hour to be crystallized, which were then fed to a 20-liter reactor for a solid-phase polymerization. Thereafter, nitrogen flowed into the reactor at a rate of 50 liters/minute. In such an event, the temperature of the reactor was raised from room temperature to 220°C at a rate of 40°C/hour and maintained. The solid-phase polymerization reaction was carried out until the intrinsic viscosity (IV) of the granules in the reactor reached 1.00 dl/g to prepare a polyester resin (copolymer).

Example 5: Preparation of a polyester resin

[0132] A 10-liter reactor equipped with a column and a condenser that can be cooled by water was charged with recycled bis(2-hydroxyethyl) terephthalate (r-BHET_A5, 4,908.6 g), TPA (566.1 g), EG (70.5 g), CHDM (1047.7 g), and a CHDM derivative (99.6 g), followed by the addition thereto of GeO_2 (6.4 g), a $\text{TiO}_2/\text{SiO}_2$ coprecipitate (0.4 g), phosphoric acid (1.0 g), cobalt acetate (0.6 g), a blue toner (0.003 g), and a red toner (0.001 g).

[0133] Subsequently, nitrogen was injected into the reactor to make the reactor pressurized by 2.0 kgf/cm² higher than normal pressure (absolute pressure: 1,495.6 mmHg). Then, the temperature of the reactor was raised to 220°C over 90 minutes and maintained at 220°C for 2 hours, and the temperature was then raised again to 250°C over 2 hours. Thereafter, an esterification reaction was carried out at a temperature of 255°C while the mixture in the reactor was visually observed until the mixture became transparent. In this procedure, by-products were discharged through the column and condenser. Upon completion of the esterification reaction, nitrogen in the pressurized reactor was released to the outside to lower the pressure in the reactor to normal pressure, and the mixture in the reactor was then transferred to a 7-liter reactor capable of a reaction under vacuum.

[0134] Then, the pressure of the reactor was reduced from normal pressure to 5 Torr (absolute pressure: 5 mmHg) over 30 minutes. At the same time, the temperature of the reactor was raised to 285°C over 1 hour, and a polycondensation reaction was carried out while the pressure of the reactor was maintained at 1 Torr (absolute pressure: 1 mmHg) or less. At the beginning of the polycondensation reaction, the stirring speed may be set high. As the polycondensation reaction proceeds, when the stirring power is weakened due to the increase in the viscosity of the reactants or the temperature of the reactants rises above the set temperature, the stirring speed may be appropriately adjusted accordingly. The polycondensation reaction was carried out until the intrinsic viscosity (IV) of the mixture (melt) in the reactor reached 0.78 dl/g. When the intrinsic viscosity of the mixture in the reactor reached the desired level, the mixture was then discharged to the outside of the reactor to form strands, which were solidified with a cooling liquid and then granulated to have an average weight of about 12 to 14 mg to prepare a polyester resin (copolymer).

Example 6: Preparation of a polyester resin

[0135] A 10-liter reactor equipped with a column and a condenser that can be cooled by water was charged with recycled bis(2-hydroxyethyl) terephthalate (r-BHET_A1, 3,104.7 g), TPA (1,660.1 g), EG (261.8 g), CHDM (992.1 g), and DEG (324.5 g), followed by the addition thereto of a $\text{TiO}_2/\text{SiO}_2$ coprecipitate (0.1 g), phosphoric acid (2.0 g), and cobalt acetate (1.4 g).

[0136] Subsequently, nitrogen was injected into the reactor to make the reactor pressurized by 2.0 kgf/cm² higher

than normal pressure (absolute pressure: 1,495.6 mmHg). Then, the temperature of the reactor was raised to 220°C over 90 minutes and maintained at 220°C for 2 hours, and the temperature was then raised again to 250°C over 2 hours. Thereafter, an esterification reaction was carried out at a temperature of 255°C while the mixture in the reactor was visually observed until the mixture became transparent. In this procedure, by-products were discharged through the column and condenser. Upon completion of the esterification reaction, nitrogen in the pressurized reactor was released to the outside to lower the pressure in the reactor to normal pressure, and the mixture in the reactor was then transferred to a 7-liter reactor capable of a reaction under vacuum.

[0137] Then, the pressure of the reactor was reduced from normal pressure to 5 Torr (absolute pressure: 5 mmHg) over 30 minutes. At the same time, the temperature of the reactor was raised to 285°C over 1 hour, and a polycondensation reaction was carried out while the pressure of the reactor was maintained at 1 Torr (absolute pressure: 1 mmHg) or less. At the beginning of the polycondensation reaction, the stirring speed may be set high. As the polycondensation reaction proceeds, when the stirring power is weakened due to the increase in the viscosity of the reactants or the temperature of the reactants rises above the set temperature, the stirring speed may be appropriately adjusted accordingly. The polycondensation reaction was carried out until the intrinsic viscosity (IV) of the mixture (melt) in the reactor reached 0.82 dl/g. When the intrinsic viscosity of the mixture in the reactor reached the desired level, the mixture was then discharged to the outside of the reactor to form strands, which were solidified with a cooling liquid and then granulated to have an average weight of about 12 to 14 mg to prepare a polyester resin (copolymer).

Example 7: Preparation of a polyester resin

[0138] A 10-liter reactor equipped with a column and a condenser that can be cooled by water was charged with recycled bis(2-hydroxyethyl) terephthalate (r-BHET_A5, 1,335.8 g), TPA (2,619.1 g), CHDM (1,969.0 g), ISB (614.3 g), and DEG (307.1 g), followed by the addition thereto of GeO₂ (32.0 g), phosphoric acid (0.2 g), a blue toner (0.015 g), and a red toner (0.005 g).

[0139] Subsequently, nitrogen was injected into the reactor to make the reactor pressurized by 1.0 kgf/cm² higher than normal pressure (absolute pressure: 1,495.6 mmHg). Then, the temperature of the reactor was raised to 220°C over 90 minutes and maintained at 220°C for 2 hours, and the temperature was then raised again to 260°C over 2 hours. Thereafter, an esterification reaction was carried out at a temperature of 265°C while the mixture in the reactor was visually observed until the mixture became transparent. In this procedure, by-products were discharged through the column and condenser. Upon completion of the esterification reaction, nitrogen in the pressurized reactor was released to the outside to lower the pressure in the reactor to normal pressure, and the mixture in the reactor was then transferred to a 7-liter reactor capable of a reaction under vacuum.

[0140] Then, the pressure of the reactor was reduced from normal pressure to 5 Torr (absolute pressure: 5 mmHg) over 30 minutes. At the same time, the temperature of the reactor was raised to 275°C over 1 hour, and a polycondensation reaction was carried out while the pressure of the reactor was maintained at 1 Torr (absolute pressure: 1 mmHg) or less. At the beginning of the polycondensation reaction, the stirring speed may be set high. As the polycondensation reaction proceeds, when the stirring power is weakened due to the increase in the viscosity of the reactants or the temperature of the reactants rises above the set temperature, the stirring speed may be appropriately adjusted accordingly. The polycondensation reaction was carried out until the intrinsic viscosity (IV) of the mixture (melt) in the reactor reached 0.70 dl/g. When the intrinsic viscosity of the mixture in the reactor reached the desired level, the mixture was then discharged to the outside of the reactor to form strands, which were solidified with a cooling liquid and then granulated to have an average weight of about 12 to 14 mg to prepare a polyester resin (copolymer).

Example 8: Preparation of a polyester resin

[0141] A 10-liter reactor equipped with a column and a condenser that can be cooled by water was charged with recycled bis(2-hydroxyethyl) terephthalate (r-BHET_A3, 532.2 g), TPA (3,516.6 g), EG (967.0 g), CHDM (268.2 g), DEG (373.9 g), a CHDM derivative (203.9 g), followed by the addition thereto of GeO₂ (3.2 g), phosphoric acid (1.0 g), a blue toner (0.025 g), and a red toner (0.010 g).

[0142] Subsequently, nitrogen was injected into the reactor to make the reactor pressurized by 0.5 kgf/cm² higher than normal pressure (absolute pressure: 1,495.6 mmHg). Then, the temperature of the reactor was raised to 220°C over 90 minutes and maintained at 220°C for 2 hours, and the temperature was then raised again to 255°C over 2 hours. Thereafter, an esterification reaction was carried out at a temperature of 260°C while the mixture in the reactor was visually observed until the mixture became transparent. In this procedure, by-products were discharged through the column and condenser. Upon completion of the esterification reaction, nitrogen in the pressurized reactor was released to the outside to lower the pressure in the reactor to normal pressure, and the mixture in the reactor was then transferred to a 7-liter reactor capable of a reaction under vacuum.

[0143] Then, the pressure of the reactor was reduced from normal pressure to 5 Torr (absolute pressure: 5 mmHg)

over 30 minutes. At the same time, the temperature of the reactor was raised to 275°C over 1 hour, and a polycondensation reaction was carried out while the pressure of the reactor was maintained at 1 Torr (absolute pressure: 1 mmHg) or less. At the beginning of the polycondensation reaction, the stirring speed may be set high. As the polycondensation reaction proceeds, when the stirring power is weakened due to the increase in the viscosity of the reactants or the temperature of the reactants rises above the set temperature, the stirring speed may be appropriately adjusted accordingly. The polycondensation reaction was carried out until the intrinsic viscosity (IV) of the mixture (melt) in the reactor reached 0.75 dl/g. When the intrinsic viscosity of the mixture in the reactor reached the desired level, the mixture was then discharged to the outside of the reactor to form strands, which were solidified with a cooling liquid and then granulated to have an average weight of about 12 to 14 mg to prepare a polyester resin (copolymer).

Example 9: Preparation of a polyester resin

[0144] A 10-liter reactor equipped with a column and a condenser that can be cooled by water was charged with recycled bis(2-hydroxyethyl) terephthalate (r-BHET_A5, 4,509.0 g), TPA (1,262.9 g), isophthalic acid (IPA, 2,946.8 g), EG (922.4 g), CHDM (182.6 g), ISB (49.4 g), and DEG (185.1 g), followed by the addition thereto of a TiO₂/SiO₂ coprecipitate (0.4 g), phosphoric acid (20.0 g), and cobalt acetate (0.8 g).

[0145] Subsequently, nitrogen was injected into the reactor to make the reactor pressurized by 3.0 kgf/cm² higher than normal pressure (absolute pressure: 1,495.6 mmHg). Then, the temperature of the reactor was raised to 220°C over 90 minutes and maintained at 220°C for 2 hours, and the temperature was then raised again to 245°C over 2 hours. Thereafter, an esterification reaction was carried out at a temperature of 260°C while the mixture in the reactor was visually observed until the mixture became transparent. In this procedure, by-products were discharged through the column and condenser. Upon completion of the esterification reaction, nitrogen in the pressurized reactor was released to the outside to lower the pressure in the reactor to normal pressure, and the mixture in the reactor was then transferred to a 7-liter reactor capable of a reaction under vacuum.

[0146] Then, the pressure of the reactor was reduced from normal pressure to 5 Torr (absolute pressure: 5 mmHg) over 30 minutes. At the same time, the temperature of the reactor was raised to 280°C over 1 hour, and a polycondensation reaction was carried out while the pressure of the reactor was maintained at 1 Torr (absolute pressure: 1 mmHg) or less. At the beginning of the polycondensation reaction, the stirring speed may be set high. As the polycondensation reaction proceeds, when the stirring power is weakened due to the increase in the viscosity of the reactants or the temperature of the reactants rises above the set temperature, the stirring speed may be appropriately adjusted accordingly. The polycondensation reaction was carried out until the intrinsic viscosity (IV) of the mixture (melt) in the reactor reached 0.60 dl/g. When the intrinsic viscosity of the mixture in the reactor reached the desired level, the mixture was then discharged to the outside of the reactor to form strands, which were solidified with a cooling liquid and then granulated to have an average weight of about 12 to 14 mg.

[0147] The granules were left at 150°C for 1 hour to be crystallized, which were then fed to a 20-liter reactor for a solid-phase polymerization. Thereafter, nitrogen flowed into the reactor at a rate of 50 liters/minute. In such an event, the temperature of the reactor was raised from room temperature to 190°C at a rate of 40°C/hour and maintained. The solid-phase polymerization reaction was carried out until the intrinsic viscosity (IV) of the granules in the reactor reached 1.10 dl/g to prepare a polyester resin (copolymer).

Comparative Example 1: Preparation of a polyester resin

[0148] A 10-liter reactor equipped with a column and a condenser that can be cooled by water was charged with recycled bis(2-hydroxyethyl) terephthalate (r-BHET_B1, 2,623.4 g), TPA (2,571.8 g), EG (1,067.3 g), CHDM (74.4 g), and ISB (50.3 g), followed by the addition thereto of GeO₂ (6.4 g).

[0149] Subsequently, nitrogen was injected into the reactor to make the reactor pressurized by 0.5 kgf/cm² higher than normal pressure (absolute pressure: 1,495.6 mmHg). Then, the temperature of the reactor was raised to 220°C over 90 minutes and maintained at 220°C for 2 hours, and the temperature was then raised again to 245°C over 2 hours. Thereafter, an esterification reaction was carried out at a temperature of 260°C while the mixture in the reactor was visually observed until the mixture became transparent. In this procedure, by-products were discharged through the column and condenser. Upon completion of the esterification reaction, nitrogen in the pressurized reactor was released to the outside to lower the pressure in the reactor to normal pressure, and the mixture in the reactor was then transferred to a 7-liter reactor capable of a reaction under vacuum.

[0150] Then, the pressure of the reactor was reduced from normal pressure to 5 Torr (absolute pressure: 5 mmHg) over 30 minutes. At the same time, the temperature of the reactor was raised to 280°C over 1 hour, and a polycondensation reaction was carried out while the pressure of the reactor was maintained at 1 Torr (absolute pressure: 1 mmHg) or less. At the beginning of the polycondensation reaction, the stirring speed may be set high. As the polycondensation reaction proceeds, when the stirring power is weakened due to the increase in the viscosity of the reactants or the temperature

of the reactants rises above the set temperature, the stirring speed may be appropriately adjusted accordingly. The polycondensation reaction was carried out until the intrinsic viscosity (IV) of the mixture (melt) in the reactor reached 0.50 dl/g. When the intrinsic viscosity of the mixture in the reactor reached the desired level, the mixture was then discharged to the outside of the reactor to form strands, which were solidified with a cooling liquid and then granulated to have an average weight of about 12 to 14 mg.

[0151] The granules were left at 150°C for 1 hour to be crystallized, which were then fed to a 20-liter reactor for a solid-phase polymerization. Thereafter, nitrogen flowed into the reactor at a rate of 50 liters/minute. In such an event, the temperature of the reactor was raised from room temperature to 200°C at a rate of 40°C/hour and maintained. The solid-phase polymerization reaction was carried out until the intrinsic viscosity (IV) of the granules in the reactor reached 0.70 dl/g to prepare a polyester resin (copolymer).

Comparative Example 2: Preparation of a polyester resin

[0152] A 10-liter reactor equipped with a column and a condenser that can be cooled by water was charged with recycled bis(2-hydroxyethyl) terephthalate (r-BHET_B2, 1,895.1 g), TPA (2,890.0 g), EG (2,719.0 g), CHDM (358.1 g), ISB (96.8 g), and DEG (36.3 g), followed by the addition thereto of a TiO₂/SiO₂ coprecipitate (0.1 g) and cobalt acetate (0.8 g).

[0153] Subsequently, nitrogen was injected into the reactor to make the reactor pressurized by 1.0 kgf/cm² higher than normal pressure (absolute pressure: 1,495.6 mmHg). Then, the temperature of the reactor was raised to 220°C over 90 minutes and maintained at 220°C for 2 hours, and the temperature was then raised again to 245°C over 2 hours. Thereafter, an esterification reaction was carried out at a temperature of 260°C while the mixture in the reactor was visually observed until the mixture became transparent. In this procedure, by-products were discharged through the column and condenser. Upon completion of the esterification reaction, nitrogen in the pressurized reactor was released to the outside to lower the pressure in the reactor to normal pressure, and the mixture in the reactor was then transferred to a 7-liter reactor capable of a reaction under vacuum.

[0154] Then, the pressure of the reactor was reduced from normal pressure to 5 Torr (absolute pressure: 5 mmHg) over 30 minutes. At the same time, the temperature of the reactor was raised to 280°C over 1 hour, and a polycondensation reaction was carried out while the pressure of the reactor was maintained at 1 Torr (absolute pressure: 1 mmHg) or less. At the beginning of the polycondensation reaction, the stirring speed may be set high. As the polycondensation reaction proceeds, when the stirring power is weakened due to the increase in the viscosity of the reactants or the temperature of the reactants rises above the set temperature, the stirring speed may be appropriately adjusted accordingly. The polycondensation reaction was carried out until the intrinsic viscosity (IV) of the mixture (melt) in the reactor reached 0.70 dl/g. When the intrinsic viscosity of the mixture in the reactor reached the desired level, the mixture was then discharged to the outside of the reactor to form strands, which were solidified with a cooling liquid and then granulated to have an average weight of about 12 to 14 mg.

[0155] The granules were left at 150°C for 1 hour to be crystallized, which were then fed to a 20-liter reactor for a solid-phase polymerization. Thereafter, nitrogen flowed into the reactor at a rate of 50 liters/minute. In such an event, the temperature of the reactor was raised from room temperature to 200°C at a rate of 40°C/hour and maintained. The solid-phase polymerization reaction was carried out until the intrinsic viscosity (IV) of the granules in the reactor reached 0.95 dl/g to prepare a polyester resin (copolymer).

Comparative Example 3: Preparation of a polyester resin

[0156] A 10-liter reactor equipped with a column and a condenser that can be cooled by water was charged with recycled bis(2-hydroxyethyl) terephthalate (r-BHET_B3, 2,715.5 g), TPA (1,774.7 g), EG (101.6 g), CHDM (1,539.5 g), ISB (41.6 g), and DEG (31.2 g), followed by the addition thereto of GeO₂ (3.2 g), phosphoric acid (0.1 g), a blue toner (0.015 g), and a red toner (0.005 g).

[0157] Subsequently, nitrogen was injected into the reactor to make the reactor pressurized by 0.5 kgf/cm² higher than normal pressure (absolute pressure: 1,495.6 mmHg). Then, the temperature of the reactor was raised to 220°C over 90 minutes and maintained at 220°C for 2 hours, and the temperature was then raised again to 255°C over 2 hours. Thereafter, an esterification reaction was carried out at a temperature of 255°C while the mixture in the reactor was visually observed until the mixture became transparent. In this procedure, by-products were discharged through the column and condenser. Upon completion of the esterification reaction, nitrogen in the pressurized reactor was released to the outside to lower the pressure in the reactor to normal pressure, and the mixture in the reactor was then transferred to a 7-liter reactor capable of a reaction under vacuum.

[0158] Then, the pressure of the reactor was reduced from normal pressure to 5 Torr (absolute pressure: 5 mmHg) over 30 minutes. At the same time, the temperature of the reactor was raised to 280°C over 1 hour, and a polycondensation reaction was carried out while the pressure of the reactor was maintained at 1 Torr (absolute pressure: 1 mmHg) or less.

At the beginning of the polycondensation reaction, the stirring speed may be set high. As the polycondensation reaction proceeds, when the stirring power is weakened due to the increase in the viscosity of the reactants or the temperature of the reactants rises above the set temperature, the stirring speed may be appropriately adjusted accordingly. The polycondensation reaction was carried out until the intrinsic viscosity (IV) of the mixture (melt) in the reactor reached 0.60 dl/g. When the intrinsic viscosity of the mixture in the reactor reached the desired level, the mixture was then discharged to the outside of the reactor to form strands, which were solidified with a cooling liquid and then granulated to have an average weight of about 12 to 14 mg to prepare a polyester resin (copolymer).

[0159] In addition, a monomer molar ratio was obtained based on the above data, and a glycol/diacid molar ratio was calculated therefrom. In addition, the content (% by weight) of r-BHET in the polyester resin was calculated. The results are shown in Tables 2 and 3.

[Table 2]

		Ex. 1	Ex. 2	Ex. 3	Ex. 4	Ex. 5	Ex. 6
Monomer molar ratio	TPA	17.50	0.00	6.32	22.47	3.41	10.00
	EG	10.75	0.42	0.76	20.97	1.14	4.22
	DEG	0.34	0.70	1.74	1.72	0.00	3.06
	CHDM	3.00	1.27	0.51	1.50	7.28	6.89
	CHDM derivative	0.00	0.00	0.00	0.00	0.37	0.00
	ISB	1.00	0.34	0.00	0.00	0.00	0.00
	r-BHET	7.50	25.36	18.95	2.50	19.33	12.22
Glycol/diacid molar ratio		1.2	2.1	1.6	1.15	2.1	1.7
r-BHET content (wt. %)		34.6	94.8	77.7	11.7	68.2	45.7

[Table 3]

		Ex. 7	Ex. 8	Ex. 9	C. Ex. 1	C. Ex. 2	C. Ex. 3
Monomer	TPA	15.78	21.18	7.61	15.49	17.41	10.69
molar ratio	EG	0.00	15.60	14.88	17.21	43.86	1.64
	DEG	2.90	3.53	1.75	0.00	0.34	0.29
	CHDM	13.67	1.86	1.27	0.52	2.49	10.69
	CHDM derivative	0.00	0.76	0.00	0.00	0.00	0.00
	ISB	4.21	0.00	0.34	0.34	0.66	0.29
	r-BHET	5.26	2.10	17.75	10.33	7.46	10.69
Glycol/diacid molar ratio		1.45	1.1	2.1	1.5	2.5	1.6
r-BHET content (wt. %)		17.2	10.0	66.0	43.7	26.4	39.9

Test Example 1: First thermal resistance index

[0160] The first thermal resistance index of the following Equation (1) was calculated for the polyester resins.

$$\text{First thermal resistance index} = \frac{(DEG_1 + 2 \times DEG_2) \times rBHET}{BHET_0} \dots (1)$$

[0161] In Equation (1), DEG_1 , DEG_2 , and $BHET_0$ are each the peak area fraction (%) of 2-hydroxyethyl[2-(2-hydroxyethoxy)ethyl] terephthalate, bis[2-(2-hydroxyethoxy)ethyl]benzene-1,4-dicarboxylate, and bis(2-hydroxyethyl) terephthalate, when the recycled bis(2-hydroxyethyl) terephthalate is measured by high-performance liquid chromatography (HPLC), and rBHET is the weight fraction (%) of recycled bis(2-hydroxyethyl) terephthalate in the polyester resin. Only

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numerical values of these parameters (DEG_1 , DEG_2 , BHET_0 , rBHET), exclusive of their units, were put in Equation (1) to calculate the first thermal resistance index (without a unit).

Test Example 2: Second thermal resistance index

[0162] The second thermal resistance index of the following Equation (2) was calculated for the polyester resins.

$$\text{Second thermal resistance index} = (G/A) \times 0.32 + 0.83 \dots (2)$$

[0163] In Equation (2), G and A are each the number of moles of glycol and the number of moles of diacid in the monomers constituting the polyester resin, and G/A is the mole ratio of glycol to diacid.

Test Example 3: Third thermal resistance index

[0164] The third thermal resistance index of the following Equation (3) was calculated using the first thermal resistance index and the second thermal resistance index obtained above.

$$\text{Third thermal resistance index} = \text{first thermal resistance index} + \text{second thermal resistance index} \quad (3)$$

Test Example 4: Intrinsic viscosity (IV)

[0165] A polyester resin was dissolved at a concentration of 0.12% in orthochlorophenol (OCP) at 150°C to obtain a solution, and an Ubbelohde viscometer was used in a constant temperature bath at 35°C to measure intrinsic viscosity. Specifically, the temperature of the viscous tube was maintained at 35°C, and the time (efflux time) required for the solvent to pass between specific internal sections of the viscous tube and the time required for the solution to pass to obtain specific viscosity, which was used to calculate intrinsic viscosity.

[0166] The intrinsic viscosity (i.e., melt IV) measured after the melt polymerization of a polyester resin (before solid-state polymerization) and the intrinsic viscosity measured after the solid-phase polymerization (i.e., solid-phase IV) are shown in Tables 4 and 5.

[Table 4]

		Ex. 1	Ex. 2	Ex. 3	Ex. 4	Ex. 5	Ex. 6
Thermal resistance index	First thermal resistance index	0.15	0.42	0.75	0.10	0.71	0.20
	Second thermal resistance index	1.22	1.51	1.35	1.21	1.51	1.38
	Third thermal resistance index	1.38	1.93	2.10	1.30	2.22	1.59
Intrinsic viscosity (dl/g)	Melt IV	0.70	0.60	0.70	0.60	0.78	0.82
	Solid-phase IV	1.20	0.85	-	1.00	-	-

[Table 5]

		Ex. 7	Ex. 8	Ex. 9	C. Ex. 1	C. Ex. 2	C. Ex. 3
Thermal resistance index	First thermal resistance index	0.18	0.10	0.68	2.34	1.84	1.49
	Second thermal resistance index	1.30	1.19	1.51	1.32	1.64	1.35
	Third thermal resistance index	1.48	1.29	2.19	3.66	3.48	2.84
Intrinsic viscosity (dl/g)	Melt IV	0.70	0.75	0.60	0.50	0.70	0.60
	Solid-phase IV	-	-	1.10	0.70	0.95	-

[0167] As can be seen from the above tables, the polyester resins of Examples 1 to 9 had a first thermal resistance index of 1.0 or less, a second thermal resistance index of 1.6 or less, and a third thermal resistance index of 2.6 or less. They were excellent in both melt intrinsic viscosity and solid-phase intrinsic viscosity.

[0168] In contrast, the polyester resins of Comparative Examples 1 to 3 had thermal resistance indices outside the preferred ranges, and their melt intrinsic viscosity and solid-phase intrinsic viscosity were relatively poor.

Test Example 5: Glass transition temperature (T_g)

[0169] The polyester resins of the Examples and Comparative Examples were each measured for the glass transition temperature (T_g). The glass transition temperature was measured at a heating rate of 10°C/minute under nitrogen using a differential scanning calorimeter (DSC1 of Mettler Toledo). The results are shown in the table below.

[Table 6]

	Ex. 1	Ex. 2	Ex. 3	Ex. 4	Ex. 5	Ex. 6
T _g (°C)	81.6	79.1	74.9	74.7	76.8	69.4
	Ex. 7	Ex. 8	Ex. 9	C. Ex. 1	C. Ex. 2	C. Ex. 3
T _g (°C)	93.5	70.7	74.8	74.3	75.5	75.2

Test Example 6: Difference in glass transition temperature (ΔT_g)

(1) Preparation of a virgin polyester resin

[0170] For the preparation of a control group, the same procedures as in Examples 1 to 9 and Comparative Examples 1 to 3 were repeated, except that the corresponding molar equivalents of ethylene glycol (EG) and terephthalic acid (TPA) were used (i.e., 2 moles of ethylene glycol and 1 mole of terephthalic acid per 1 mole of recycled BHET were used), instead of recycled BHET, to polymerize a virgin polyester resin.

(2) The polyester resins (virgin resins) prepared in step (1) above were each measured for the glass transition temperature (T_g). The glass transition temperature was measured by the same method as in Test Example 5. Then, ΔT_g was calculated according to the following equation, and the results are shown in the table below.

$$\Delta T_g (^\circ\text{C}) = T_{g1} - T_{g2}$$

[0171] Here, T_{g2} is the glass transition temperature (°C) of a polyester resin polymerized using recycled BHET, and T_{g1} is the glass transition temperature (°C) of a polyester resin polymerized using ethylene glycol and terephthalic acid in molar equivalents to the recycled BHET.

[Table 7]

	Ex. 1	Ex. 2	Ex. 3	Ex. 4	Ex. 5	Ex. 6
ΔT _g (°C)	1.4	1.9	2.1	1.3	2.2	1.6
	Ex. 7	Ex. 8	Ex. 9	C. Ex. 1	C. Ex. 2	C. Ex. 3
ΔT _g (°C)	1.5	1.3	2.2	3.7	3.5	2.8

[0172] As can be seen from the above results, the polyester resins of Examples 1 to 9 had a very small decrease in glass transition temperature as compared with the virgin resins, whereas the polyester resins of Comparative Examples 1 to 3 had a large decrease in glass transition temperature.

Claims

1. A polyester resin, which comprises recycled bis(2-hydroxyethyl) terephthalate obtained through the depolymerization of waste polyester, wherein the recycled bis(2-hydroxyethyl) terephthalate has a peak area fraction of bis(2-hydroxyethyl) terephthalate of 96% or more and a peak area fraction of 2-hydroxyethyl[2-(2-hydroxyethoxy)ethyl] terephthalate of 2.5% or less, when measured by high-performance liquid chromatography (HPLC).
2. The polyester resin of claim 1, wherein the recycled bis(2-hydroxyethyl) terephthalate has a peak area fraction of

bis[2-(2-hydroxyethoxy)ethyl]benzene-1,4-dicarboxylate of 0.2% or less when measured by high-performance liquid chromatography (HPLC).

3. The polyester resin of claim 1, wherein the polyester resin has a first thermal resistance index of 1.0 or less as calculated from the following Equation (1):

$$\text{First thermal resistance index} = \frac{(DEG_1 + 2 \times DEG_2) \times rBHET}{BHET_0} \dots (1)$$

in Equation (1), DEG_1 , DEG_2 , and $BHET_0$ are each the peak area fraction (%) of 2-hydroxyethyl[2-(2-hydroxyethoxy)ethyl] terephthalate, bis[2-(2-hydroxyethoxy)ethyl]benzene-1,4-dicarboxylate, and bis(2-hydroxyethyl) terephthalate, when the recycled bis(2-hydroxyethyl) terephthalate is measured by high-performance liquid chromatography (HPLC), and $rBHET$ is the weight fraction (%) of recycled bis(2-hydroxyethyl) terephthalate in the polyester resin.

4. The polyester resin of claim 1, wherein the polyester resin comprises a diacid component and a glycol component,

the diacid component comprises at least one selected from the group consisting of terephthalic acid, isophthalic acid, dimethyl isophthalate, phthalic acid, dimethyl phthalate, phthalic anhydride, 2,6-naphthalenedicarboxylic acid, dimethyl 2,6-naphthalenedicarboxylate, diphenyl dicarboxylic acid, 1,4-cyclohexanedicarboxylic acid, 1,3-cyclohexanedicarboxylic acid, dimethyl 1,4-cyclohexanedicarboxylate, dimethyl 1,3-cyclohexanedicarboxylate, sebacic acid, succinic acid, isodecylsuccinic acid, maleic acid, maleic anhydride, fumaric acid, adipic acid, glutaric acid, and azelaic acid, and

the glycol component comprises at least one selected from the group consisting of isosorbide (ISB), ethylene glycol, 1,2-propanediol, 1,3-propanediol, 2-methyl-1,3-propanediol, 2-methylene-1,3-propanediol, 2-ethyl-1,3-propanediol, 2-isopropyl-1,3-propanediol, 2,2-dimethyl-1,3-propanediol, 1,4-butanediol, 2,3-butanediol, 3-methyl-1,5-pentanediol, 3-methyl-2,4-pentanediol, 1,6-hexanediol, 1,2-cyclohexanediol, 1,4-cyclohexanediol, diethylene glycol, 4-(hydroxymethyl)cyclohexylmethyl-4-(hydroxymethyl)cyclohexanecarboxylate, and 4-(4-(hydroxymethyl)cyclohexylmethoxymethyl)cyclohexylmethanol.

5. The polyester resin of claim 3, wherein the polyester resin has a second thermal resistance index of 1.6 or less as calculated from the following Equation (2):

$$\text{Second thermal resistance index} = (G/A) \times 0.32 + 0.83 \dots (2)$$

in Equation (2), G and A are each the number of moles of glycol and the number of moles of diacid in the monomers constituting the polyester resin, and G/A is the mole ratio of glycol to diacid.

6. The polyester resin of claim 5, wherein the polyester resin has a third thermal resistance index of 2.6 or less as calculated from the following Equation (3):

$$\text{Third thermal resistance index} = \text{first thermal resistance index} + \text{second thermal resistance index} \dots (3).$$

7. The polyester resin of claim 1, wherein the polyester resin has an intrinsic viscosity (IV) at 35°C of 0.5 dl/g to 1.2 dl/g.

8. The polyester resin of claim 1, wherein the recycled bis(2-hydroxyethyl) terephthalate is employed in an amount of 5% by weight to 99% by weight based on the weight of the polyester resin.

9. The polyester resin of claim 1, wherein the recycled bis(2-hydroxyethyl) terephthalate has a yellow index (YID) of 3.0 or less as measured with a spectrophotometer in a solution of 25% by weight.

10. A process for preparing a polyester resin, which comprises:

polymerizing a polyester resin using recycled bis(2-hydroxyethyl) terephthalate (BHET) obtained through the

depolymerization of waste polyester,

wherein the recycled bis(2-hydroxyethyl) terephthalate has a peak area fraction of bis(2-hydroxyethyl) terephthalate of 96% or more and a peak area fraction of 2-hydroxyethyl[2-(2-hydroxyethoxy)ethyl] terephthalate of 2.5% or less, when measured by high-performance liquid chromatography (HPLC).

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11. The process for preparing a polyester resin of claim 10, wherein the recycled bis(2-hydroxyethyl) terephthalate is prepared by the following steps:

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(1) subjecting waste polyester to depolymerization by a first glycolysis reaction at a temperature of 180°C to 200°C to obtain a first reactant;

(2) subjecting the first reactant to depolymerization by a second glycolysis reaction at a temperature of 150°C to 170°C to obtain a second reactant;

(3) subjecting the second reactant to ion exchange through an ion-exchange resin to obtain a third reactant;

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(4) removing an unreacted glycol from the third reactant through distillation at a temperature of 150°C or lower to obtain a fourth reactant; and

(5) subjecting the fourth reactant to distillation to obtain crude bis(2-hydroxyethyl) terephthalate.

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12. The process for preparing a polyester resin of claim 11, wherein the waste polyester has a particulate or fibrous form with a particle diameter of 4 mm or less.

13. An article, which comprises the polyester resin of any one of claims 1 to 9.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2023/002933

A. CLASSIFICATION OF SUBJECT MATTER C08G 63/00(2006.01)i; C08G 63/16(2006.01)i; C08J 11/10(2006.01)i According to International Patent Classification (IPC) or to both national classification and IPC																					
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) C08G 63/00(2006.01); C07C 67/03(2006.01); C07C 67/52(2006.01); C07C 67/54(2006.01); C07C 69/82(2006.01); C08J 11/20(2006.01); C08J 11/24(2006.01); C08L 67/02(2006.01) Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Korean utility models and applications for utility models: IPC as above Japanese utility models and applications for utility models: IPC as above Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) eKOMPASS (KIPO internal) & keywords: 재생(recycle), 비스(2-히드록시에틸)테레프탈레이트(bis(2-hydroxyethyl)terephthalate, BHET), 폴리에스테르(polyester), 불순물(impurity), 당분해(glycolysis)																					
C. DOCUMENTS CONSIDERED TO BE RELEVANT <table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>X</td> <td>WO 2021-028695 A1 (POSEIDON PLASTICS LIMITED) 18 February 2021 (2021-02-18) See abstract; claims 1-25; pages 2-31; and figure 3.</td> <td>1-3,5-6,9-10,13</td> </tr> <tr> <td>Y</td> <td></td> <td>4,7-8,11-12</td> </tr> <tr> <td>Y</td> <td>KR 10-2020-0061948 A (LOTTE CHEMICAL CORPORATION) 03 June 2020 (2020-06-03) See claims 5-7; paragraphs [0023]-[0089]; and table 1.</td> <td>4,7-8</td> </tr> <tr> <td>Y</td> <td>KR 10-2019-0026737 A (IFP ENERGIES NOUVELLES) 13 March 2019 (2019-03-13) See paragraphs [0060]-[0063].</td> <td>11-12</td> </tr> <tr> <td>A</td> <td>KR 10-2021-0067554 A (LOTTE CHEMICAL CORPORATION) 08 June 2021 (2021-06-08) See entire document.</td> <td>1-13</td> </tr> <tr> <td>A</td> <td>US 2004-0019234 A1 (INADA, S. et al.) 29 January 2004 (2004-01-29) See entire document.</td> <td>1-13</td> </tr> </tbody> </table>	Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	X	WO 2021-028695 A1 (POSEIDON PLASTICS LIMITED) 18 February 2021 (2021-02-18) See abstract; claims 1-25; pages 2-31; and figure 3.	1-3,5-6,9-10,13	Y		4,7-8,11-12	Y	KR 10-2020-0061948 A (LOTTE CHEMICAL CORPORATION) 03 June 2020 (2020-06-03) See claims 5-7; paragraphs [0023]-[0089]; and table 1.	4,7-8	Y	KR 10-2019-0026737 A (IFP ENERGIES NOUVELLES) 13 March 2019 (2019-03-13) See paragraphs [0060]-[0063].	11-12	A	KR 10-2021-0067554 A (LOTTE CHEMICAL CORPORATION) 08 June 2021 (2021-06-08) See entire document.	1-13	A	US 2004-0019234 A1 (INADA, S. et al.) 29 January 2004 (2004-01-29) See entire document.	1-13
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Date of the actual completion of the international search 30 May 2023	Date of mailing of the international search report 30 May 2023																				
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2023/002933

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